

CHAPTER 1

INTRODUCTION

1.1 Background of Research

The emerging field of nanoscience aims to create new materials with length scales of approximately 1-100 nanometers, ranging from macromolecules to nanoscale solid, and to understand the fundamental of new phenomena displayed by these nanoscale materials. It has stimulated interdisciplinary research at the interfaces of chemistry, physics, biology, and engineering sciences, and it is also the cornerstone for the discovery and development of revolutionary nanotechnology¹.

Semiconductor technology is one of the fields that dominated by the revolutionary of nanotechnology now. The trend toward miniaturization, dominating the technological progress of the past decades, corresponds to the demands for faster operation and less heat dissipation. Furthermore, the rapid development of the semiconductor technology, including epitaxy techniques for preparation of even single-molecular layers of materials, lithography methods, and advances in

controlling self-aggregation processes, results in quite new possibilities for artificial creation of ultra small physical system with controlled properties².

Silicon is at the center of today's modern electronics consumer industry. Since there is a trend towards ever smaller electronic devices, microelectronics may eventually go over to nanoelectronics and maybe the key technology in the 21st century³. Silicon becomes the preferred material for single-electron and quantum-electronic devices from a practical point of view are due to the reason that mature technologies can be used during the fabrication process⁴. This is a definite advantage in developing commercial devices. Research into the practical uses of silicon single-electron and quantum-electronic devices began in the early 1990s when the fabrication of nanostructures in silicon became possible owing to the continuous reduction of device size in LSI circuits for higher integration and performance.

Silicon nanodots, also known as silicon quantum dots or silicon nanocrystal, consist of 100s-1000s of atoms and are approximately one billionth of a meter in size. It becomes the interest of research work due to its specific structure, electronic and optical properties. The latter was stimulated by the discovery of efficient light emission in different forms of silicon nanostructures⁵ and by the demonstration of a silicon-based light-emitting device prototype integrated into conventional microelectronic circuitry⁶. Hence, the interest in reliable fabrication of silicon-based nanostructures with control over the nanocrystal size, shape, and crystallographic orientation has been growing continuously the last decade. Recently, the application of silicon nanocrystals in electronic devices was suggested and proved by the demonstration of a silicon nanocrystal nonvolatile memory and other devices utilizing the coulomb bloackage effect^{7,8}.

In general, there are two philosophically distinct approaches for creating

silicon nanostructure, which can be characterized as top down and bottom up. In the conventional top-down approach, nanostructures are patterned in bulk materials by a combination of lithography, etching and deposition to form functional devices. This approach has greatly pushed nanoscience research forward during the past few decades, although efforts to push the resolution down to a few nanometers will face scientific challenges intrinsic to the top-down approach. Recently the bottom-up approach to form nanometer-scaled silicon structures with silicon nanodots are attracting us more particularly for future nanoelectronics and quantum information device applications.

Bottom-up, or self-assembly, approaches is the nanofabrication technique which use chemical or physical forces operating at the nanoscale to assemble basic units into larger structures⁹. The latter has two subdisciplines, physical vapor-deposition (PVD) and chemical vapor deposition (CVD). The difference between the last two is that in PVD the actual active species are directly evaporated or injected into the gas phase; in CVD, a precursor is used that, on transporting into the vapour space, is chemically decomposed into the required species¹. The key advantage of bottom-up approach is that critical nanoscale features are defined during synthesis, and this can yield uniform structures at the atomic scale.

Despite the research history for silicon nanodots is still short, but we believe that the unique properties of silicon nanodots will make it a strong candidate for a major application of nanotechnology in the future including the single electron transistor. Thus, in order to understand on how silicon nanodot is being formed, an in depth knowledge of nucleation, i.e. an early stage of the formation of stable nuclei from the gas/liquid/solid phases, its growth process, and the control of fabrication process become a pre-requisite requirement for those working in this area.

1.2 Research Objectives

- To study the theory of nucleation and growth of silicon nanodots and predict the related parameters.
- To set up the Radio Frequency (RF) Magnetron Sputtering system for the fabrication of samples.
- To determine the optimum experimental conditions for the fabrication of silicon self-assembled nanodots.
- To analyze and interpret the results obtained from the characterization measurements.

1.3 Research Scopes

Recently the bottom–up approach to form nanometer- scaled silicon structures with silicon nanodots are attracting researchers for future nanoelectronics and quantum information device applications. In this research, the very early stage of nanodots formation known as nucleation and the assembly of nano-sized islands have been investigated theoretically and experimentally. The sapphire has been chosen as substrate. Samples of silicon nanodots are fabricated using a RF magnetron sputtering under different experimental conditions, and further investigation on the optimum operational parameters. The following setting parameters are identified: Deposition times vary from 5 to 20mins, substrate temperatures between 100 °C to 400 °C and finally the RF powers ranging from 50-200W. Characterization measurements are performed using Atomic Force Microscope (AFM),

Photoluminescence Spectroscopy (PL) and X-Ray Diffraction (XRD). In addition, analysis using Energy Dispersive X-ray Spectrometry (EDX) has been conducted to confirm the contents of nanodots.

1.4 Research Problems

Self-assembly has become very effective and promising approach to synthesize a wide range of novel nanoscale materials due to unexpected physical properties that the self-aggregated nanoparticles show. Research on silicon nanostructures has a great attention with the excitement that the size range of silicon nanostructures start exhibiting novel properties that are both quantitatively and qualitatively different from those of their respective bulk materials and from the discrete atoms or molecules which they are derived.

Thus, the fabrication of silicon nanodots have been investigated in many research works which will be discussed in Chapter 2. It is found that the study for early stage growth of silicon nanodots still less been reported. A lot of works has been concentrated to study the nucleation and growth of GaN on sapphire based on the large lattice mismatch that evokes the Volmer-Weber growth. It is observed that the large lattice mismatch also appear between silicon and sapphire. In order to investigate the self-assembly growth of silicon nanodots following the Volmer-Weber growth mode in the early stage of film growth, the sapphire substrate has been chosen as substrate. The RF sputtering system has been chosen as the technique to fabricate the silicon nanodots on sapphire in this research since it has been reported as promising technique to produce silicon nanocrystals in many research works.

In order to better understand the nucleation and growth mechanisms of the silicon nanodots, the capillarity approximation of nucleation theory has been studied. A computing program has been developed based on the quantitative description of nucleation theory. The influences of temperature, surface energy and contact angle to the critical size and critical energy have been predicted theoretically.

In the following, the morphology and microstructural evolution of the silicon nucleation layer as the function of growth time also been reported in this research. The effect of substrate temperature and rf power to the surface morphology, silicon composition, photoluminescence and X-ray diffraction results have been investigated.

1.5 Layout of Thesis

This thesis is comprised of 5 chapters. The first contains an overview of research background and specified the aim of studies, choice of system, and outline of the thesis plan. Chapter 2 discusses the previous work done, theory of self assembled growth, nucleation and fabrication techniques. The following chapter 3 covers the simulation setup, sample preparation, setup of the system, design of the experiment and also methods of measurement and characterization. Chapter 4 presents the simulation and experimental results obtained in this work with the details discussion. Finally, the conclusion of the project is made in chapter 5. It also includes the summarization of the whole project and some recommendations for future work.